ERDC TN-EMRRP-ER-04
October 2006

Guidelines for the Acquisition of Aerial Photography for Digital Photo-Interpretation of Submerged Aquatic Vegetation (SAV)

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PURPOSE: Monitoring the success of large-scale submerged aquatic vegetation (SAV) restoration projects requires the ability to detect and map the presence or absence of SAV, as well as assess changes in SAV distributions over time. Aerial photography is generally considered to be the most widely used, versatile, and relatively economical form of remote sensing (Lillesand and Kiefer 2000), and is the most common source of SAV mapping information (McKenzie et al. 2001). More often than not, however, difficulties arise that result in an undesirable or sometimes unusable photographic product.

The intent of this technical note is to provide a clear understanding of the procedures and requirements involved for the acquisition of aerial photography, specifically for mapping submerged aquatic vegetation (SAV) via digital photo-interpretation, as shown in Figure 1. It is anticipated that the contract specifications detailed within this document can be used on a system-wide basis as a standardized template by U.S. Army Corps of Engineers (USACE) employees seeking guidance for contracting the acquisition of aerial photography for SAV mapping purposes. The recommendations and contract specifications reflect proven techniques implemented by USACE for the purpose of mapping SAV for monitoring trends and change detection. Advanced procedures, in contrast to traditional photo-interpretation, through the use of a stereoscope and stereo-paired photos, include the use of digital image products to visually extract SAV from scanned photography. This greatly improves efficiency and production of an SAV dataset and automatically produces a digital dataset to be incorporated into a Geographic Information System (GIS).

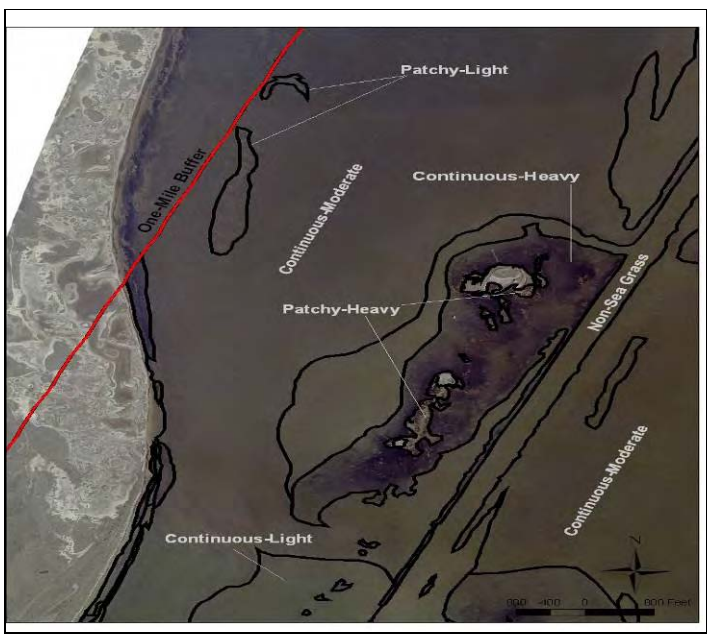

Figure 1. Aerial view of SAV classification based on spatial distribution and density

BACKGROUND: This technical note is based on experience obtained from contracting the acquisition of analog aerial photography for the purpose of mapping SAV in the Laguna Madre Intracoastal Waterway in south Texas for the USACE Galveston District. Included within this document are details related to the production of digital orthorectified photography, produced from analog aerial photography, which can be viewed

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
OCT 2006	**N/A**	**-**

4. TITLE AND SUBTITLE
Guidelines for the Acquisition of Aerial Photography for Digital Photo-Interpretation of Submerged Aquatic Vegetation (SAV)

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Engineering Research and Development Center Vicksburg, MS 39180

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**10**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

as an improved method to mapping SAV via traditional techniques as described by Leonard (1984) and Dardeau (1983). It is worth noting that although many USACE publications have been dedicated to mapping SAV from aerial photography, none of them thoroughly reviews procedures to map SAV from orthorectified digital images while simultaneously incorporating the information into a GIS. Therefore, this technical note will emphasize these procedures in addition to the standard requirements involved for contracting aerial photography for SAV mapping purposes.

The recommendations provided in this document are offered as guidance only and may not be suitable for every mapping application. Although many aspects are addressed, some modifications may be necessary to account for specific elements unique to an individual project. Due to the complexity and variability of associated costs for contracting services, project costs will not be discussed, but are nonetheless a very important consideration. A general knowledge of photogrammetry and remote sensing may be required to fully comprehend the underlying, technical aspects of this document; however, the intent is to provide the fundamentals necessary to specify the appropriate products suitable to meet project objectives when communicating with an aerial services contractor.

PLANNING: Probably the single most important aspect of any successful project is proper planning. The primary purpose of planning is to lay out precise, realistic objectives and desired outcomes of relevant tasks, while staying within budget and a preset timeframe. Visual image interpretation from aerial photography for the purpose of mapping SAV primarily seeks to assess the present condition of the seagrass at the landscape level. This initial data collection, or baseline, can then be used to monitor long-term changes in seagrass distribution and cover over time. The planning phase is also a good time to configure a sampling design for the collection of ground truth data to perform an accuracy assessment of SAV interpretation results. All ground truth data should be collected as close to the photography acquisition date as possible, preferably at the same time, so that conditions are similar. Sampling data to be used for ground truth should be randomly placed throughout the study area to minimize bias in the interpretation results. A common sampling design to accomplish this would involve stratified random sampling; the number of points should be derived based on the project's required percent accuracy and allowable error. The objective of the ground truth is to verify the presence or absence of SAV for developing an accuracy assessment and to identify other features of interest such as macroalgae or similar vegetation that may be confused with SAV.

It is usually beneficial, although not always possible, for aerial services contractors to be located near the project area and to be familiar with acquiring photography for mapping SAV. They will be familiar with the process and will be more accustomed to the strict weather requirements associated with this type of data acquisition. In addition, their close proximity will allow for rapid deployment. Due to the variability in weather and water clarity conditions, daily coordination with the contractor may be necessary in order to determine if suitable conditions exist prior to executing the flight.

CONTRACT SPECIFICATIONS: Providing the contractor with specific collection parameters will help minimize confusion and will save both time and money throughout the project. In fact, neglecting some of these mission-critical inputs could cause acquisition delays or result in an incompatible product. Specific contract requirements critical to SAV mapping are addressed in more detail below.

Timing: Timing of the photography acquisition is critical in order to adequately detect the presence of SAV and must be a top priority from the beginning to avoid untimely delays and ensure

successful data capture. A number of factors must be considered. First, the photography must be acquired during periods when aboveground material is present in sufficient quantities to be readily observable. In general, the optimum period for acquisition will be during the active growing season from late spring to late summer (May through September). However, there will be some exceptions. For example, with respect to the Laguna Madre project, late fall and early winter is often the optimum time for acquisition of aerial photography for the purpose of mapping SAV resources. During this time, visualization of plants is enhanced due to seasonally lower tidal elevations and reduced water column turbidity. Although there are seasonal differences in plant biomass, sufficient aboveground material persists year-round to enable adequate detection and mapping of SAV distribution.

The effect of tides on image quality and SAV detection should also be considered. In areas with large daily tidal ranges, the increased water depth during high tide may hinder detection of SAV beds. Therefore, surveys may need to coincide with lower tide levels in order to increase visibility. If possible, it is best to complete the flight the same day to have consistent weather, water, and atmospheric conditions. It is also beneficial to specify the time of day, within a collection window of opportunity, when favorable environmental conditions exist that are conducive to mapping. For the Laguna Madre project, ideal conditions were most probable beginning in November and extending to April during the morning hours, when there was a low sediment load and calm winds.

Finally, if the purpose of the photography acquisition involves monitoring potential changes in SAV distribution as a result of some event, such as SAV restoration planting or dredging and disposal operations, it is important to establish a monitoring protocol that takes into account the time of the occurrence in relation to flight planning and data acquisition. Baseline surveys are often necessary to document pre-project SAV conditions. It is highly recommended that multiple years of baseline data be collected, in order to document normal inter-annual variability in SAV distribution. Natural inter-annual variability in SAV biomass can be substantial, yet is seldom considered due to the limited duration of most studies (Nelson 1997). In addition, if repeated annual surveys are to be performed, particularly for change detection, it is important that photographs be collected at approximately the same time each year to minimize the effects of seasonal variability in SAV distribution and biomass.

Environmental Conditions: Many other factors must be considered when developing a scope of work and establishing contract specifications. Certain requirements exist (particularly weather-related) for mapping SAV from an aerial platform (Figure 2). These requirements include, but may not be limited to:

- Calm wind (minimize waves that interfere with SAV interpretation).
- Sun angle between 30° and 45° above the horizon (minimize glare and reflection from the water surface).
- Good water clarity (very low sediment load).
- Minimal cloud cover (less than 5 percent).

Figure 3 illustrates the amount of variability during very poor conditions and near perfect conditions with respect to SAV interpretation.

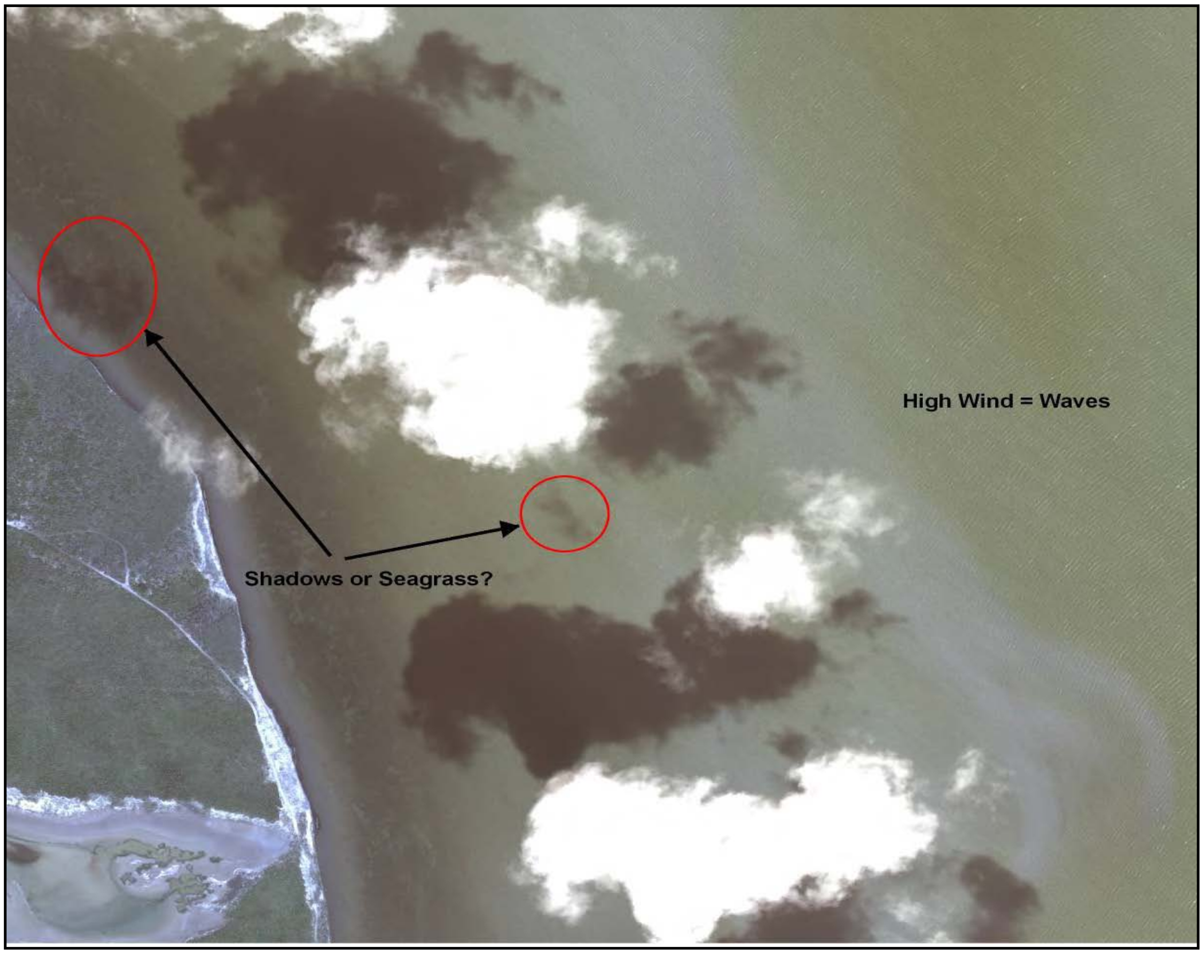

Figure 2. Negative environmental conditions (clouds, wind, high sediment, etc.) greatly reduce SAV photo interpretation

Figure 3. Image on left depicts poor conditions (clouds, high sediment load, and high winds). Image on right illustrates near optimal conditions (acquisition date appears at lower right in each image)

Film: Generally speaking, true color photography (analog or digital) is best suited for mapping SAV for most monitoring applications when the vegetation is completely submerged below the water column. Due to haze and color discrimination, a panchromatic black and white film is usually not recommended but could be used for interpreting approximate seagrass bed locations or to assess present conditions if other options were not available. Because near-infrared light is absorbed in only a few decimeters of the water surface and red wavelengths only penetrate to depths of a few meters (Lillesand and Keifer 2000), infrared film is much less effective (when compared to color film) at recording benthic features in shallow, moderately turbid water and is therefore usually not recommended for most benthic mapping applications (Finkbeiner et al. 2001). However, infrared photography may be applicable under certain conditions. For example, it has been used in the Pacific Northwest to map intertidal SAV and macroalage during periods when they are exposed to air during low tide (Young et al. 1998).

Scale: Determining the appropriate scale for SAV mapping is multi-faceted. Factors to consider include the coverage, extent and type of habitat, desired spatial resolution, and the degree of water clarity. Often, tradeoffs exist that may affect the scale chosen and one must evaluate each factor accordingly. For example, if areas adjacent to the habitat area are of interest, specifying an extra percentage of overlap and/or sidelap will provide supplemental data but will likely increase cost if scale remains constant. Photographic scale for general benthic mapping normally ranges from 1:12,000 to 1:48,000. Under most circumstances, a scale of 1:24,000 represents a good balance between area coverage and small-feature detection (minimum mapping unit of 0.25 acre) and it also corresponds to the USGS 7.5-min topographic quad maps (Finkbeiner et al. 2001). For persistently turbid water, a scale of 1:12,000 (or larger) may be required for acceptable visualization and discrimination of submerged features, and even then only during times of low turbidity or sediment load. It is suggested that for extensive areas of relatively clear water, a scale of 1:48,000 may be sufficient and cost-effective. However, for detecting small inter-annual changes in SAV distribution, a scale of 1:10,000 or less may be necessary (McKenzie et al. 2001).

Data Products/Delivery: Seagrass interpretation can often be improved through the use of a digital product such as an orthorectified photographic mosaic, because it gives the interpreter the ability to zoom in or out from the digital image and view the data at variable display scales. Even though this capability enables better discrimination of questionable areas, the SAV should be interpreted and digitized at a consistent scale to avoid biasing the results. An orthorectified photograph, or orthophoto, is similar to a map in which scale, tilt, and relief distortions (inherent from an aerial platform) have been removed, producing an image that can be readily interpreted and true distances, angles, and area can be directly measured (Lillesand and Kiefer 2000). Traditional analog photographs are scanned at a maximum density (to produce very small pixel sizes, or high spatial resolution) and rectified using various ancillary data sources such as ground control points (GCPs) and other digital, rectified images such as USGS Digital Orthophoto Quarter Quads (DOQQs) or derived Digital Elevation Models (DEMs). The end product is a very high resolution image that, when used along with the stereopair contact prints, can greatly improve interpretive analysis of the seagrass. It also enables simultaneous generation of a geo-referenced spatial data layer that can be overlaid with other forms of Geographic Information Systems (GIS) data.

Some details that must be considered during flight planning and acquisition will assist in the subsequent production of these digital products. Since adequate ground control is crucial for rectification,

it is important to establish flightlines that maximize the use of the coastline, if possible, or ensure that the contractor is equipped with a full camera inertial movement system. If static features along the coastline cannot be used to establish ground control and no inertial system is available, the contractor may need to place temporary floating markers for ground control. Measuring features in the image on the ground with survey equipment or a Global Positioning System (GPS) will establish instant GCP measurements. It is best to generate GCPs after the photos have been acquired and scanned so that points can be distributed throughout each frame and placed at a large aspect ratio to provide an optimal geometric solution in the rectification process. In most cases, it is sufficient to have at least three (preferably four with a few extra for backup) GCPs in each photo frame, or one point in each quadrant of the frame (Figure 4). For areas that have overlapping flightlines, additional points are recommended to ensure that soon-to-be delineated SAV polygons on adjacent frames are not out of position with one another.

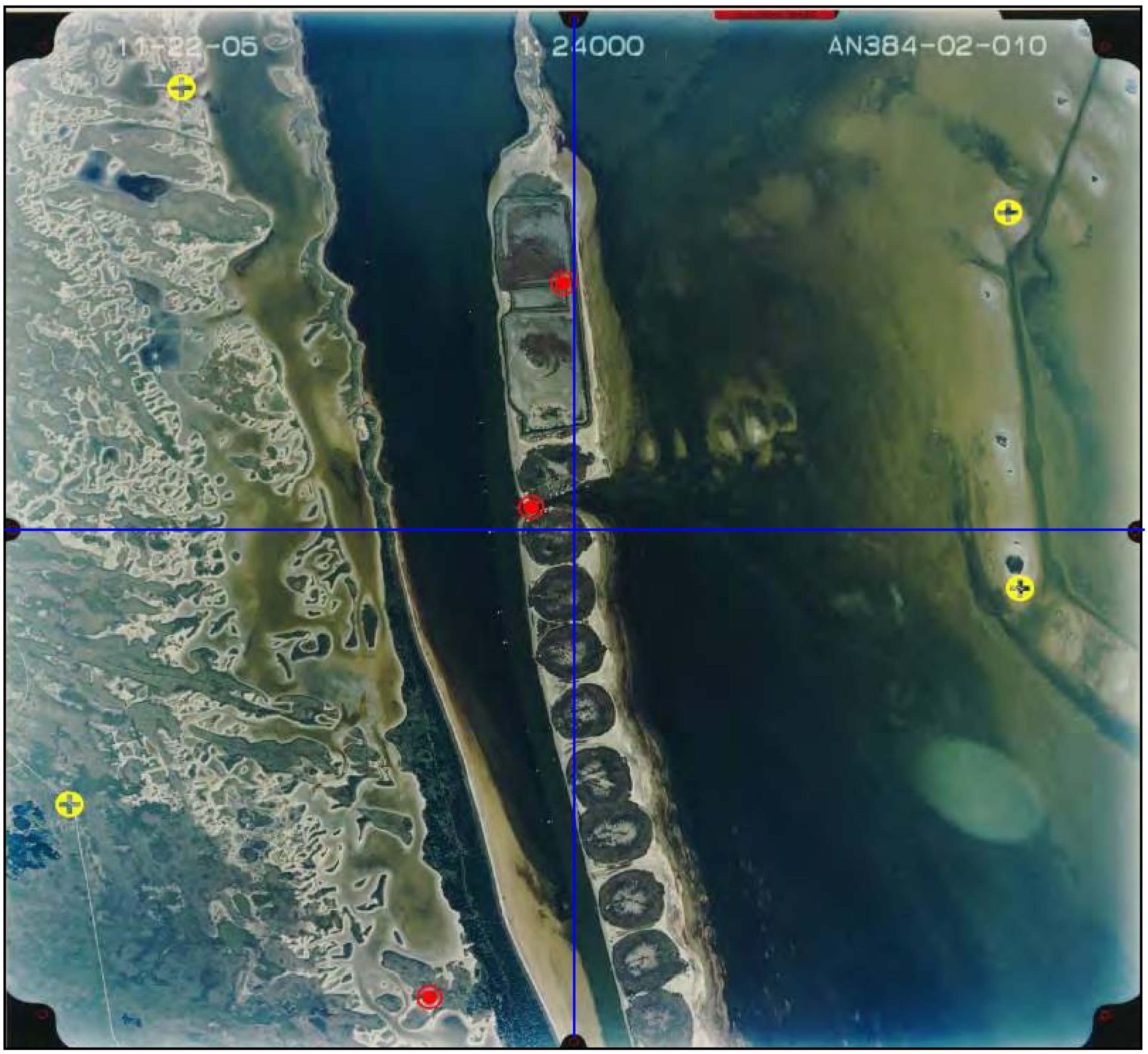

Figure 4. Optimal allocation of control points in each quadrant of the photo frame (yellow symbols). Additional control points (red symbols) can be used if initial points do not provide an adequate orthographic solution

Refraction in the water can also complicate the generation of orthophoto production, but is usually a minor source of error, given the shallow depths of water and the level nature of the bottom floor in such situations. With the previous recommendations in mind, it is very important to specify the desired end product(s) that will meet the project objectives. It is also beneficial to specify a suitable delivery date after data collection has been completed to take receipt of the finished product.

Additional specifications may include items such as bounding coordinates detailing the exact locations of the study area (a map is very helpful) and a suitable deliverable format for the data (stereo-paired contacts or an orthocorrected digital mosaic). It is important to clearly document all of these requirements in a contractual agreement, such as a Statement of Work (Appendix A), with the contractor and ensure that all requirements are fully understood before work begins.

ACKNOWLEDGMENTS: Publication of this report was jointly funded by the Ecosystem Management and Restoration Research Program (EMRRP) and the Chesapeake Bay Submerged Aquatic Vegetation Research Program. The EMRRP Technical Director at the time of publication was Dr. Al Cofrancesco and the Program Manager was Mr. Glenn Rhett. Program Manager of the Chesapeake Bay Submerged Aquatic Vegetation Research Program was Ms. Deborah J. Shafer. The work was performed under the direction of the Ecosystem Evaluation and Engineering Division (EE) of the Environmental Laboratory (EL), U.S. Army Engineer Research and Development Center (ERDC).

The authors would like to thank the following for their support regarding this project: Mr. Terry Roberts, Mr. Michael Nelson, and Mr. David Petit of the USACE Galveston District; Mr. Michael Bishop and Mr. Scott Bourne of EL, and Dr. Mark Finkbeiner of the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center for their shared expertise.

At the time of publication, Director of EL was Dr. Beth Fleming and Chief of EE was Dr. David J. Tazik. Dr. James R. Houston was Director of ERDC, and COL Richard B. Jenkins was Commander.

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> Jackson, S. S., M. R. Graves, and D. J. Shafer. 2006. *Contracting guidelines for the acquisition of aerial photography for digital photo-interpretation of submerged aquatic vegetation (SAV).* EMRRP Technical Notes Collection (ERDC TN-EMRRP-ER-04). Vicksburg, MS: U.S. Army Engineer Research and Development Center. *http://el.erdc.usace.army.mil/*

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Appendix A. Sample Contract

STATEMENT OF WORK FOR AERIAL PHOTOGRAPHIC DATA COLLECTION FOR THE TEXAS SEGMENT OF THE GULF INTRACOASTAL WATERWAY SEAGRASS MAPPING PROJECT

1 **DESCRIPTION OF SERVICES.** The contractor shall provide all personnel, equipment, tools, supervision, and other items and services necessary to ensure that the aerial photographs taken and subsequent products generated for approximately 117 miles of the Texas Intracoastal Waterway Seagrass Mapping Project are collected and processed such that in post-processing, the sub-aquatic seagrass communities are visible for mapping.

1.1 **DATA CONSTRAINTS.**

1.1.1 **Environmental Conditions.** Because the intent of this data collection effort is to provide materials for mapping subaqueous seagrass communities, the environmental conditions are of prime importance. The water surface in the Texas Intracoastal Waterway will need to be smooth (i.e. with the wave effects of wind nonexistent or minimized). Also, water clarity during photo acquisition is extremely important. The aerial photos must be collected at a time when sediment load is at a state such that the seagrasses are visible on the photos.

1.1.2 **Time Frame of Data Collection.** Due to the typical environmental conditions in the area, photography should be obtained by the end of April 2004. However, if environmental conditions permit — namely, no wind and clear water conditions — data can be acquired up to June 30, 2004. We require that the vender coordinate the data collection flight plan with the government POC for verification that environmental conditions listed above will be met.

1.1.3 **Contact Government POC for Mission Study Area Description.** The vendor will contact the government POC for transfer of an ESRI Shapefile that describes the specific target areas of interest and flightlines for this mission. We will require that the vendor contact us by phone no more than 24 hours before the mission is flown for verification of acceptable water clarity. Vendor is responsible for ensuring acceptable wind conditions prior to data acquisition. NOTE: No photos will be accepted which are acquired during windy conditions which prohibit visualization of subaqueous seagrasses. An image of the study area can be found in Figure A-1.

2 **PRODUCT DELIVERY SUMMARY.**

2.1 **Aerial Photographs.** The aerial photographs should be collected at a nominal scale of 1:24,000 (or 1' = 2000"). The film should be true color and there should be stereo coverage for the entire 117 miles (approximate) of study area. One copy of the true color negatives and one true color paper print for each of the photos will be included in the deliverables.

2.2 **Photograph Scan Density.** The photos are to be scanned at a scan density so as to produce pixel sizes equivalent to 1.5x1.5 feet of ground surface or less. A copy of the digital photos will be included in the deliverables and will be an ESRI ArcGIS-readable format on either cd/rom or DVD media.

2.3 **Digital Terrain Model.** The scanned aerial photos are to be used as input in the generation of a stereoscopic, computer-generated Digital Terrain Model (DTM). A copy of the DTM will be included in the deliverables and will be an ESRI ArcGIS-readable format on either cd/rom or DVD media.

2.4 **Digital Elevation Model.** A Digital Elevation Model (DEM) is to be computer generated from the Digital Terrain Model. A digital copy of the DEM will be included in the deliverables and will be an ESRI ArcGIS-readable format on either cd/rom or DVD media.

2.5 **Orthocorrected Photo Mosaic.** A digital orthophoto mosaic is to be generated using the DTM-generated DEM for the elevation source, the aerial photos collected for this mission for image information, and USGS Digital Orthophoto Quarter Quads for ground control. A copy of the orthocorrected photo mosaic will be included in the deliverables and will be an ESRI ArcGIS-readable format on either cd/rom or DVD media.

2.6 **Performance Threshold Measures**.

2.6.1 Products must conform to National Mapping Accuracy Standards (NMAS) for 1:24,000 scale.

2.6.2 Photo clarity must be sufficient to allow for mapping of subaqueous seagrasses including wind conditions, water clarity, and atmospheric clarity.

2.6.3 No photos will be accepted which are acquired during windy conditions which prohibit visualization of subaqueous seagrasses.

2.6.4 Coverage of the entire study area should be obtained during the same day, if possible.

3 GOVERNMENT FURNISHED PROPERTY AND SERVICES.

3.1 **Point of Contact.** The government will provide all contact information necessary for POCs for flight plan verification.

3.2 **Coordinates of Study Area.** The government will provide an ESRI shapefile to the vendor that describes the center line of the study area to be photographed for the approximately 117 miles of Texas Intracoastal Waterway.

4 GENERAL INFORMATION.

4.1 **National Mapping Accuracy Standards.** The vendor will assure that the digital data products meet or exceed the National Mapping Accuracy Standards (NMAS) for 1:24,000 scale.

4.2 **Data Delivery.** The vendor will deliver all products by mission flight date plus 90 days.